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AMRL MEMORANDUM P-21

CONTROLLED ROTATION AND STABILIZATION FOR THE
ORBITAL WORKER

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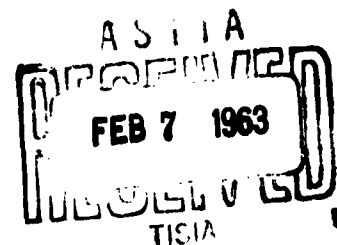Behavioral Sciences Laboratory

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Flight Control Section
Flight Vehicle Branch
Operational Support Engineering Division

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6570th AEROSPACE MEDICAL RESEARCH LABORATORIES
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I INTRODUCTION*

   In the past, considerable effort has been expended to provide a self-maneuvering unit (ref. 2 and 3) for an orbital worker who must perform maintenance, supply, and inspection tasks on or between space vehicles. One essential component of such a unit is a continuously acting stabilization system. This provides the worker with a stable self-oriented reference frame by which he may judge position, velocity, and acceleration. This type of stabilization can best be provided by momentum wheels which rotate uniformly in the manner of a gyroscope. Since a rotating wheel tends to remain in its plane of rotation in the absence of external forces, the capability for stabilization is provided. Likewise, since a rotating wheel tends to change its plane of rotation with the application of force moments (torques), the capability for controlled rotation is provided. This report serves to develop the principles of controlled rotation and incorporate them in a feasible stabilization-rotation system.

A self-contained stable platform has been designed for the free-floater and is now being fabricated. The intent of this Gyro Augmented Stabilization Pack (hereafter referred to as the GASP) is to offer tumble recovery, controlled rotation and stability capabilities to a weightless worker.

The primary problem of adopting gyroscopic principles for the purpose of a stable platform for free-floating personnel is one of control. A gyroscopic element has inherent stability in two axes. By providing two gyroscopic elements, stability can be obtained in three axes. Thus, the primary effort in this study is to develop a geometric configuration for two gyroscopic elements which lend themselves to control in three axes with 360° of freedom in each axis. The word control as applied herein is to be interpreted as control of rotational modes occurring in the three mutually perpendicular axes.

The following definitions of symbols are used in this section:

H————————————Angular Momentum of Rotor (lb-ft-sec)

$J_Y = J_X = J$————————Moment of Inertia of Element M about the Center of Mass of the system (lb-ft-sec^2)

L————————————Torque Arm (ft)

T_X————————————Torque Input about x-axis (ft-lb)

Try————————————Reaction Torque about y-axis (ft-lb)

Trx————————————Reaction Torque about x-axis (ft-lb)

K————————————Spring constant (lb/ft)

t————————————Time (sec)

M————————————Man

$\left[\dfrac{d\theta_i}{dt}\right]_Y$————————Input rate about Y-axis (degrees/sec)

$\left[\dfrac{d\theta_o}{dt}\right]_X$————————Output rate about X-axis (degrees/sec)

$\left[\dfrac{d\theta_o}{dt}\right]_Y$————————Output rate about Y-axis

Consider a gyroscopic element G in Figure 1 located in some random position with respect to inertial space. A coordinate system x, y, and z is superimposed on element G with the origin at the center of mass of the element. This reference system rotates with element G in respect to inertial space. The man who is to be stabilized and controlled is represented by a cylinder element M. A set of rotating coordinates x', y', and z' are established as shown. In the initial condition y is parallel to y',
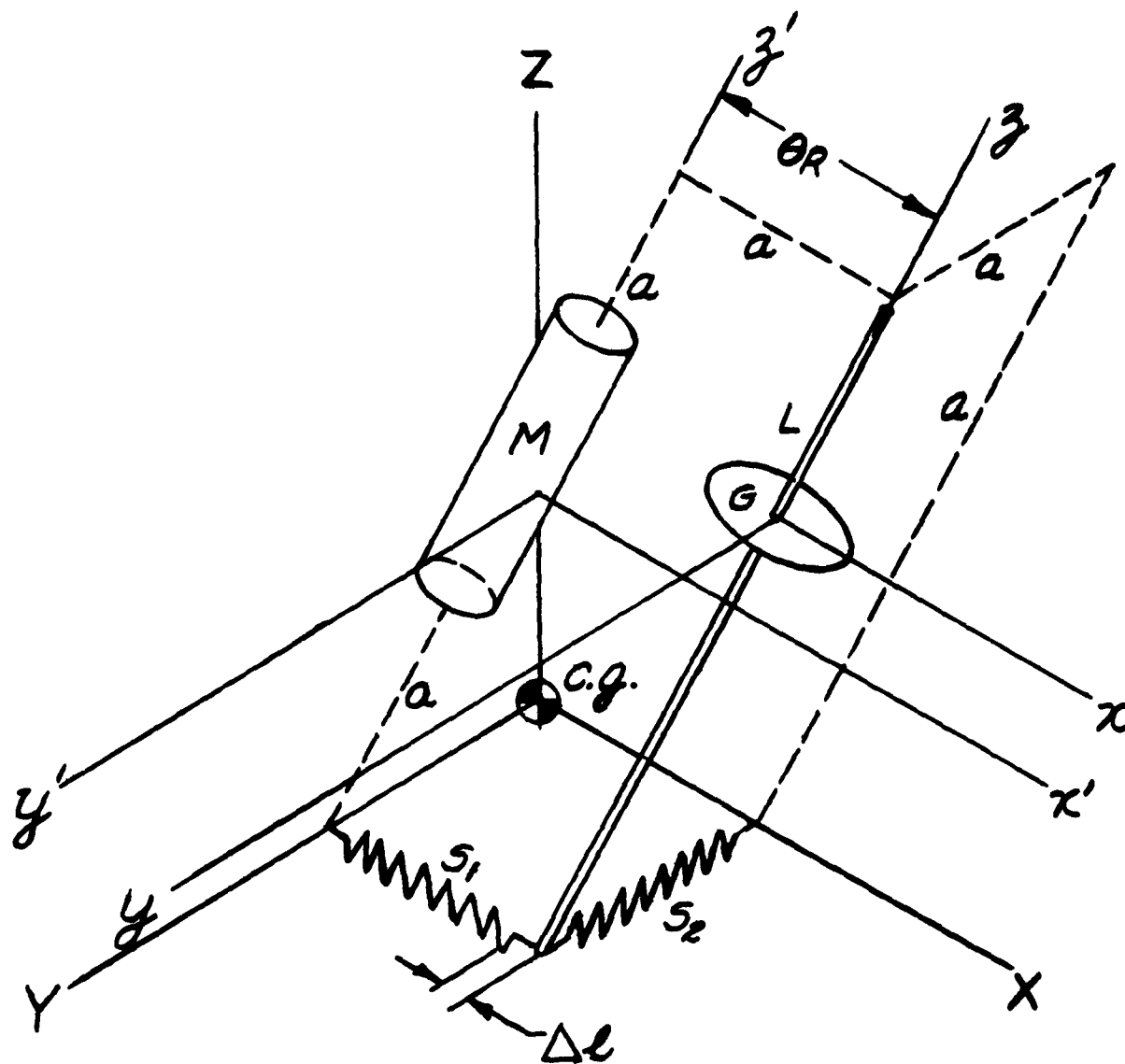

FIGURE 1 Schematic of System Co-ordinates

x parallel to x', and z parallel to z'. Element M is attached to element G by rigid but weightless structures. Two mechanical springs S_1 and S_2 are provided which couple the other end of element G to element M. In the initial condition the axes of S_1 and S_2 are parallel to x' and x, and y' and y respectively.

The purpose of these springs are to:

a. Allow means of torquing element G in two axes.

b. Provide means of transmitting precession of element G to element M.

Another reference system X, Y, and Z is established and fixed with respect to inertial space. The origin of this coordinate system is located at the center of mass of the combined mass of element G and M. At the initial condition Y is parallel to y and X is parallel to x.

Consider a torque, T_x, about the x axis acting on element G. At the application of T_x, a precession occurs about y. This precession is considered the rotational input to the system. Therefore:

$$T_X = H \left[\frac{d\theta_i}{dt} \right]_y \qquad (1)$$

The sub y denotes precession about the y axis. The term $\left[\frac{d\theta_i}{dt} \right]$ is merely the rate of precession about y. Since all rotational modes must take place about the center of mass of the system and if equation (1) is to remain true, equation (1) should be changed to:

$$T_X = H \left[\frac{d\theta_i}{dt} \right]_Y \qquad (2)$$

Here sub Y denotes that the precession is about Y. Other sub notations will be used in this manner throughout this section.

The term $\left[\frac{d\theta_i}{dt} \right]$ is now considered the input to the system about the Y or y axes. Using this input, equations of motion will be derived for outputs occurring about Y and X which results from T_X.

Since element M has inertia, a force will be experienced in S_1 as the result of a finite deflection Δl. The reaction torque Try, therefore, imposed upon element M is equal to:

$$T_{Ry} = KL\Delta l \qquad (3)$$

Compression of S_1 by Δl results in an angular displacement, θ_R, between the z' and z axes. Therefore, the following relationships are true:

$$\Delta l = L\theta_R$$
$$\theta_R = t \left[\frac{d\theta_R}{dt} \right] \qquad (4)$$

Substituting the above equations into equation (3) yields:

$$T_{Ry} = KL^2 t \left[\frac{d\theta_R}{dt} \right] \qquad (5)$$

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But noting that $\frac{d\theta_R}{dt}$ is the difference in the angular rotation of z' and z about y' and y, $\frac{d\theta_R}{dt}$ becomes equal to:

$$\frac{d\theta_R}{dt} = \left(\left[\frac{d\theta_i}{dt}\right]_Y - \left[\frac{d\theta_o}{dt}\right]_{y'} \right) \qquad (6)$$

Since $\left[\frac{d\theta_o}{dt}\right]_{y'}$ cannot occur about y' and if equation (6) is to remain true, equation (6) must be rewritten as:

$$\frac{d\theta_R}{dt} = \left(\left[\frac{d\theta_i}{dt}\right]_Y - \left[\frac{d\theta_o}{dt}\right]_Y \right) \qquad (7)$$

Substituting equation (7) into equation (5) gives:

$$T_{Ry} = KL^2t \left(\left[\frac{d\theta_i}{dt}\right]_Y - \left[\frac{d\theta_o}{dt}\right]_Y \right) \qquad (8)$$

Equating the torque in equation (8) to the time rate of change of angular momentum of M yields the differential equation of motion of the system about the Y axis:

$$J_Y \left[\frac{d^2\theta_o}{dt^2}\right]_Y + KL^2t \left[\frac{d\theta_o}{dt}\right]_Y = KL^2t \left[\frac{d\theta_i}{dt}\right]_Y \qquad (9)$$

The solution to equation (9) is:

$$\left[\frac{d\theta_o}{dt}\right]_Y = \left[\frac{d\theta_i}{dt}\right]_Y \left[1 - e^{-\frac{KL^2t}{2J_y}}\right] \qquad (10)$$

Equation (10) does not represent all the dynamics of the system. Equation (10) gives the component of rate about the Y axis as the result of T_x. As $\left[\frac{d\theta_i}{dt}\right]_Y$ is being transmitted to M, the reaction torque Try exerts a torque on G about the Y axis. A precession of G will, therefore, occur about the X axis. It, therefore, becomes necessary to compute the input to the system about the X axis resulting from Try. It is evident that:

$$T_{Ry} = H \left[\frac{d\theta_i}{dt}\right]_x \qquad (11)$$

Since rotation must take place about the center of mass of the system and if equation (11) is to remain valid, it must be rewritten as:

$$T_{Ry} = H \left[\frac{d\theta_i}{dt}\right]_X \qquad (12)$$

Substituting equation (8) into equation (12) gives:

$$KL^2t \left(\left[\frac{d\theta_i}{dt}\right]_Y - \left[\frac{d\theta_o}{dt}\right]_Y \right) = H \left[\frac{d\theta_i}{dt}\right]_X \qquad (13)$$

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Substituting equation (10) into equation (13) yields:

$$\left[\frac{d\theta_i'}{dt}\right]_X = \frac{KL^2 t}{H}\left(\left[\frac{d\theta_i}{dt}\right]_Y - \left[\frac{d\theta_i}{dt}\right]_Y \left\{1 - e^{-\frac{KL^2 t^2}{2J_y}}\right\}\right) \tag{14}$$

Equation (14) represents the input about the X axis resulting from the input about the Y axis. The output about the X axis as the result of the input about the X axis shall now be derived. From the argument put forth up to equation (8), it is obvious that the reaction torque, Trx, about X is equal to:

$$T_{RX} = KL^2 t\left(\left[\frac{d\theta_i}{dt}\right]_X - \left[\frac{d\theta_o}{dt}\right]_X\right) \tag{15}$$

Equating the time rate of change of angular momentum of M about X to equation (15) yields:

$$J_X\left[\frac{d^2\theta_o}{dt^2}\right]_X + KL^2 t\left[\frac{d\theta_o}{dt}\right]_X = KL^2 t\left[\frac{d\theta_i}{dt}\right]_X \tag{16}$$

Noting that equation (14) reduces to:

$$\left[\frac{d\theta_i'}{dt}\right]_X = \frac{KL^2 t}{H}\left[\frac{d\theta_i}{dt}\right]_Y e^{-\frac{KL^2 t^2}{2J_Y}} \tag{17}$$

and substituting into equation (16) yields:

$$J_X\left[\frac{d^2\theta_o}{dt^2}\right]_X + KL^2 t\left[\frac{d\theta_o}{dt}\right]_X = \frac{K^2 L^4 t^2}{H}\left[\frac{d\theta_i}{dt}\right]_Y e^{-\frac{KL^2 t^2}{2J_Y}} \tag{18}$$

Equation (18) is the equation of motion governing rotation about the X axis as the result of an input, $\left[\frac{d\theta_i}{dt}\right]_Y$, about the Y axis.

The solution to equation (18) yields:

$$\left[\frac{d\theta_o}{dt}\right]_X = \frac{K^2 L^4 t^3}{3 H J_Y}\left[\frac{d\theta_i}{dt}\right]_Y e^{-\frac{KL^2 t^2}{2J_Y}} \tag{19}$$

From equation (19) it becomes obvious that an input about the Y axis does not result in a pure output about the Y axis, but a component of the input occurs as an output about the X axis. The usability of the configuration shown in Figure 1 depends upon the amount of cross-coupling represented by equation (19). It should be understood that if the initial input was about the X axis, equation (10) would describe the output about the X axis and equation (19) would describe the cross-coupling about the Y axis.

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For the purpose of this discussion only one condition will be considered since conclusions drawn from one condition will be true for the other. By choosing typical values for parameters noted in the list of definitions, a plot of equations (10) and (19) have been made and given in Figure 2. The ordinate axis of this graph is the ratio of the output to input. Thus, if any given input rate is multiplied by the given scale, the output can therefore be read from the scale for any given time. The character-istics of the coupling affect is also shown. The absolute angle turned through as the result of this affect is the integral of $[\frac{d\theta}{dt}]_x$. This integral is represented by the area under the curve. This area will not be computed here but, for an input rate of 5 rpm this area is estimated to be approximately 2 degrees. This coupling affect is considered negligible. These curves also show that the cross coupling affect disappears completely after 0.6 seconds. For any input about the Y axis, 99% of the desired output is reached within 0.5 seconds. It is, therefore, concluded that the configuration shown in Figure 1 is adequate for controlability in two axes.

At this point certain assumptions which have been made above shall be mentioned which may not be immediately obvious. The entire system shown in Figure 1 has been considered isolated from any gravitational forces (zero gravity conditions). Thus, no supporting structures or gimbaling systems are needed to fix the system in reference to the X, Y, and Z axes. This study was conducted from the standpoint that the zero gravity condition would last approximately 20 seconds. The gyro wheel has been con-sidered as a constant speed wheel although no power inputs have been considered. The wheel may be brought up to speed by some external frictional device which is removed when the zero gravity conditions are established. Since the operating period is 20 seconds or less, the initial rotary energy in the wheel is great enough to substain stability and control over this short time period. It is true that the energy needed to control element M must come from element G. Thus, the wheel is not actually a constant speed wheel. The response curves in Figure 2 are based upon a wheel speed of 1750 rpm. In the actual hardware an rpm of 3000 rpm is expected. Thus, equations (10) and (19) represent average conditions of the actual equipment operating between 3000 rpm and 1750 rpm. The zenith of element M is in the positive z' axis; there-fore, J_x can be considered to be equal to J_y without introducing serious errors.

In the foregoing discussion, response equations were developed showing feasibility of a single gyroscopic element for control about two axes. Another gyroscopic element must be added to the system shown in Figure 1 for control about the other axis. If the other two axes are established as pitch and roll in respect to element M, then the second gyroscopic element must be arranged to control rotation in the azimuth axis. Figure 3 shows one such arrangement of a second gyroscopic element in relation to the first. The gimbaled gyro may rotate completely about the X axis. For a pure pitch maneuver (rotation about the X axis), gimbal A remains fixed and the system rotates about the spin axis of the second gyroscopic element. Thus, for pitch and roll control, the second gyroscopic element has no adverse affect. If a torque is applied to gimbal A about the X axis, a rotation or output will occur about the Z axis, (azimuth). Thus, azimuth control has no affect upon the first gyroscopic elements since its axis is parallel to the axis of rotation. No calculations are given here for the response of the second gyroscopic element. Although the second element is not mounted directly to the frame, as is the first gyroscopic element, the response of the second element will be as good or better than that of the first.

In order to mechanize the system shown in Figure 3 a control stick has to be developed such that torque can be applied around the X and Y axes of element G and around the X axis of the second gyroscopic element. The torquing mechanism must be arranged so torque can be applied separately to each axis or in any combination. During a pitching maneuver torquing the second gyroscopic element becomes more complicated since a requirement may exist to torque this axis in the same direction as any pitching that may be taking place. This control requirement can be satisfied by adding a differential gear on the X axis of the second element. Such a device can be arranged to allow torquing to this axis regardless of pitching rates.

The greatest disadvantage of the configuration shown in Figure 3 occurs as the system is in a control azimuth maneuver and the operator wishes to superimpose a roll maneuver at an instant when the spin axis of the second element makes an angle other than 90° with the spin axis of the first element. If a roll maneuver is attempted under these conditions, roll will not take place until the second element precesses to a 90° relationship with the first element. The effects of this inherent hesitation of the system upon an operator's confidence of control is unknown. Also, cross-coupling effects during the hesitation period will be greater. In practice, the hesitation may not even be noticed by the operator. It is conceivable that the operator can "over-control" in such a manner that cross-coupling effects will take place in two axes and thus cancel each other. If this proves to be the case all cross-coupling effects can be removed entirely.
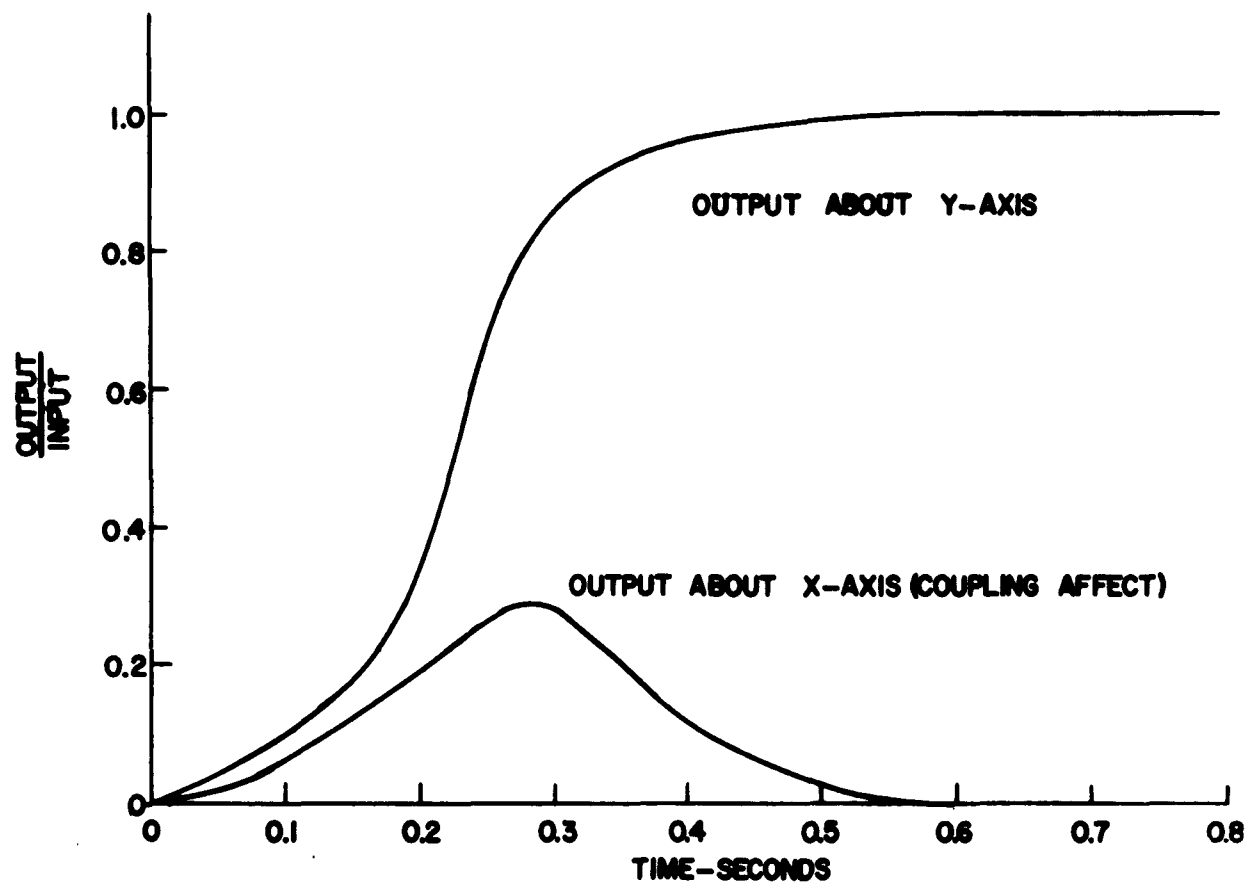
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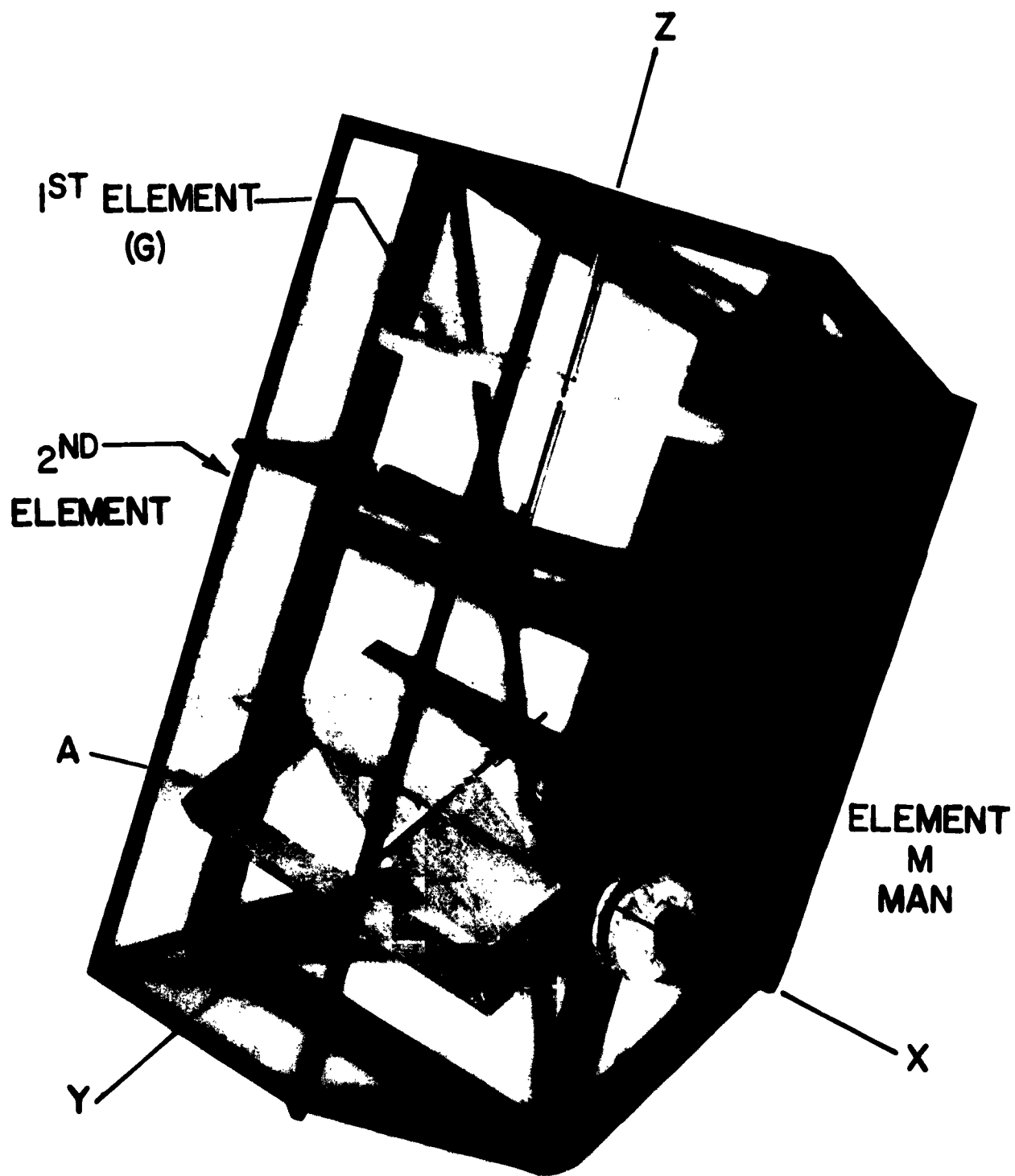FIGURE 2 Response Curves for Input About Y-axis

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FIGURE 3 Mock-up of Gyroscopic Elements

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III GYRO AUGMENTED STABILIZATION PACK FABRICATION*

As a result of the preceding analysis a prototype of the proposed configuration (shown in Fig. 4) has been constructed. However, actual testing of the GASP has been delayed until better control modes have been fabricated.

The major problems regarding the operation of the GASP may be placed in three groups: revving up to and maintaining a high angular velocity of each wheel, torquing the gyros to cause precession of the operator, and developing a control device to service complete control of rotation about a set of mutually perpendicular coordinate axes.

Revving the wheels to a high angular velocity is accomplished by placing each wheel in contact with a motor driven friction wheel. The motor and its special fittings are shown in Figure 5. Using this method to impart angular momentum to each rotor, however, has two disadvantages. First, the gimbaled gyro must be placed at right angles to the ungimbaled gyro if controlled rotations are to be most efficient; yet when the wheels are revved up, the gyros are parallel as shown in Figure 6. Thus, the act of displacing the gimbaled gyro to its most functional orientation will cause the operator to yaw about the Z axis, prior to each planned maneuver. Second, the motor is massive and must be rigidly latched in the GASP frame, and hence the procedure of detaching the motor from the frame at zero gravity conditions may be unwieldy. For use as an aid in evaluating this stabilization system, though, the induced yaw will be accepted as an inconvenience while techniques will be developed to minimize the awkwardness of detaching the motor from the frame. Yet, it will be necessary to adapt other means of revving the wheels up if the GASP is developed further.

Torquing the wheels to cause precession of the operator is a problem only in determining the most efficient method of torquing. Due to the preliminary nature of this study, the use of an applied force directed by the operator, through a wire cable, to the spin axis of a wheel was selected as the torquing mechanism. However, this system is undesirable mainly due to excessive friction losses in the pulleys and rollers which are required to guide the cables. These friction losses, as well as the congestion resulting from the number and placement of cables, can be eliminated by using hydraulic pressure to torque the wheels. The use of hydraulics has an added advantage in that the control stick now under development could be readily converted to apply hydraulic forces.

The control stick, however, poses a unique problem, since a control stick may often be given one or two degrees of freedom as limited by control requirements. Yet, it is desirable to incorporate three degrees of freedom in a single control stick of a stabilization unit for orbital workers. The primary criterion for such a selection is based upon control-vehicle motion compatibility. Briefly stated, this and other important criteria are:

FIGURE 4 Gyro Augmented Stabilisation Pack
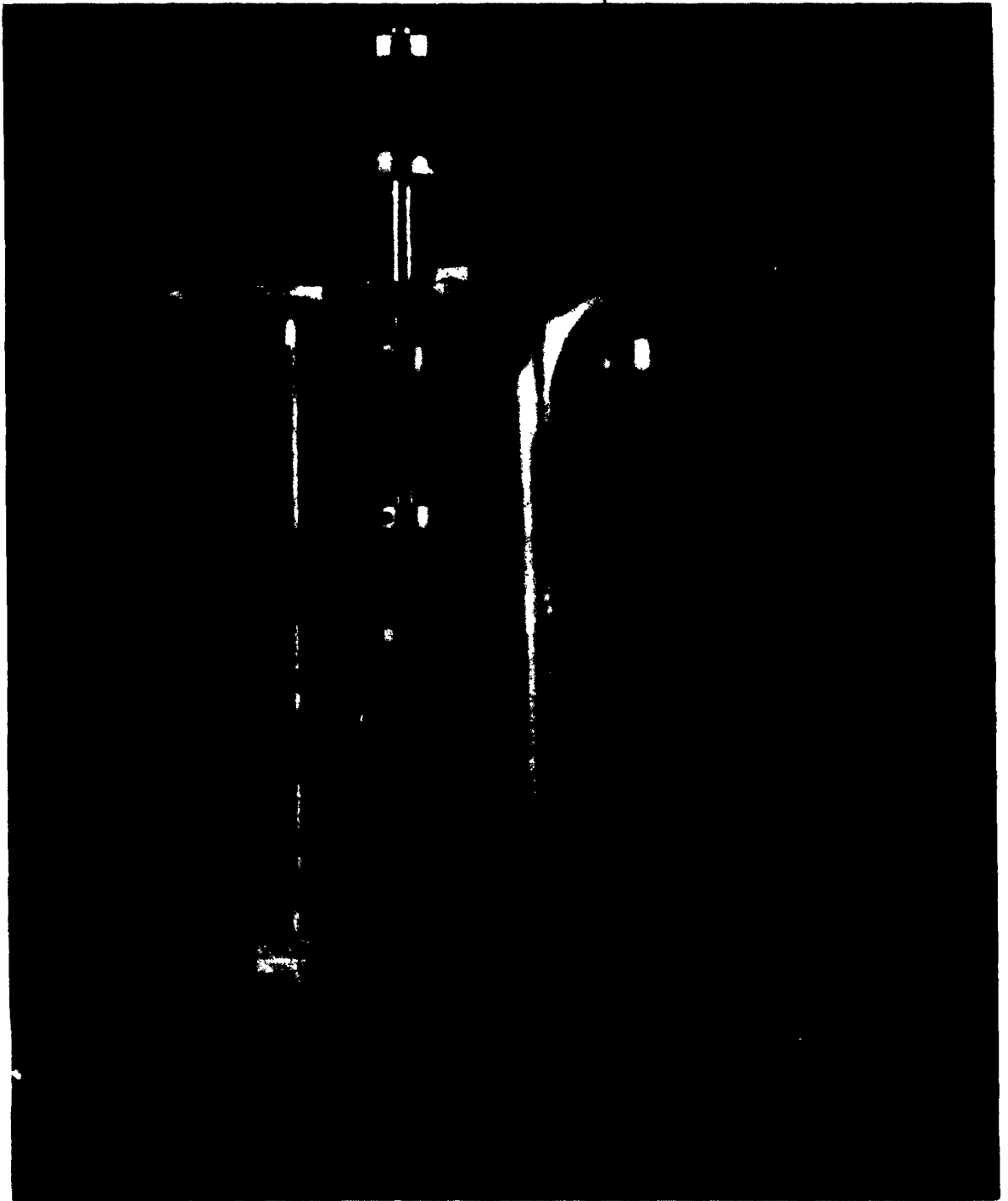
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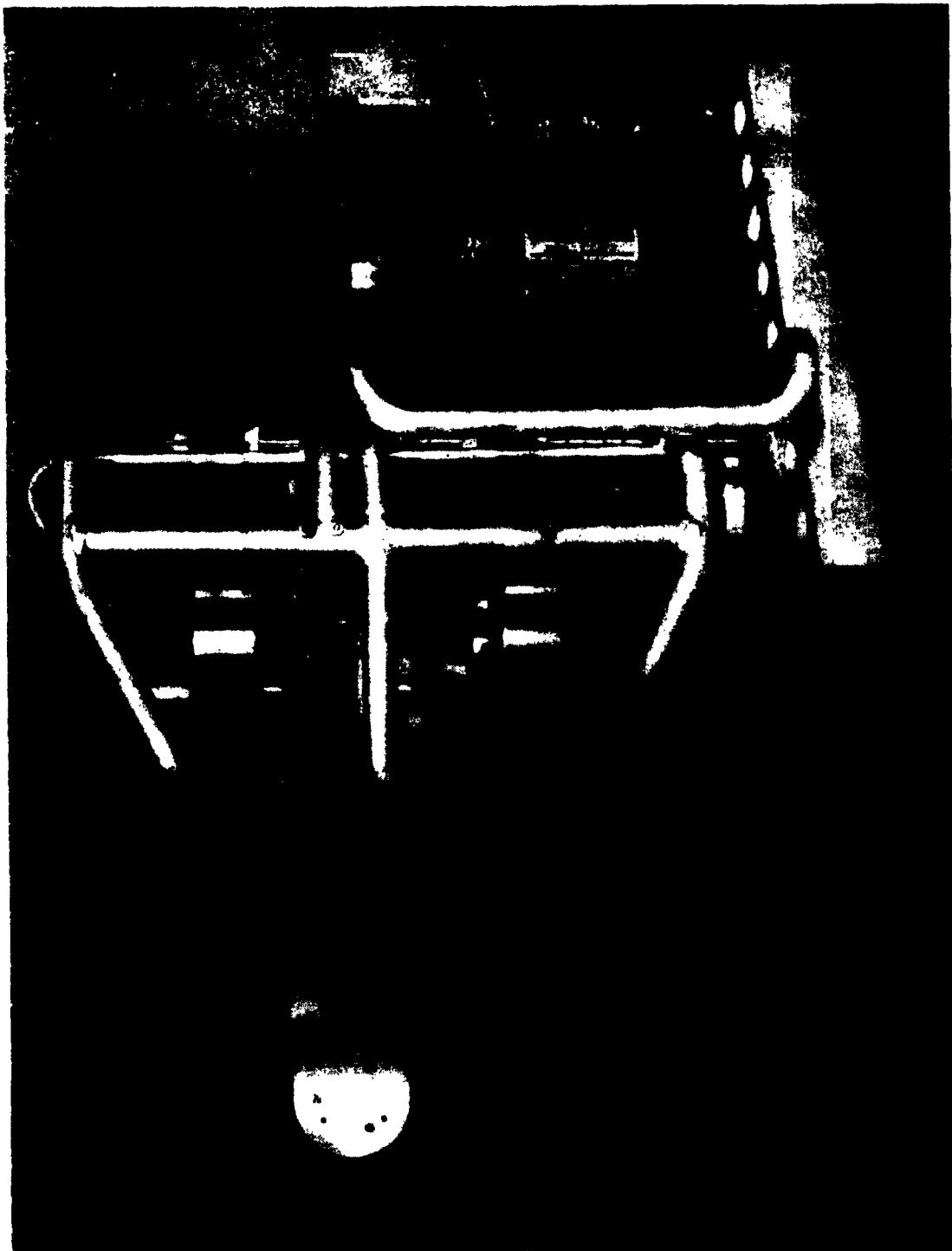FIGURE 5   Gyro Actuator Motor

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FIGURE 6 Gyro-Motor Mesh Assembly

1. Since man becomes a vehicle while using a self-maneuvering unit (SMU), it is convenient to relate the motions available to a vehicle to the motions available to the individual using an SMU. The vehicle whose motion capabilities are similar to an orbital worker is the airplane, and thus we may classify the rotational capabilities (outputs) of the orbital worker as pitch, roll, and yaw. Therefore, in the design of the controller, it is desirable to incorporate the capability of moving the controller (inputs) in the same direction as the proposed rotation (outputs) as shown in Figure 7.

2. By keeping the three control modes in the same device, distinct time losses in hand movements between controls are eliminated if one hand is to be used to control the rotation. This effect becomes more pronounced if full pressure suits are to be used due to limb restrictions imposed by the suit.

3. Decision making between control modes may be eliminated if the control operation can be made instinctive, as may be maximized by having one mechanism control all rotations.

4. If a single three axis controller is used, one of the operator's hands may be free at all times to aid task performance.

In keeping with these criteria, a contoller is now being developed, and upon its completion, a validation of the entire GASP will be performed.

Operation of the GASP

It may be desirable to briefly discuss first the torques that must be applied and their points of application.

The torques that a weightless worker will have to apply to the momentum wheels must originate with some displacement of the control stick. This displacement will immediately apply tension to a cable, which transmits the force to a point on the spin axis of the gyro. It is this application of force to the spin axis which causes the gyro, and also the operator, to precess. If this force has a magnitude of P, if the top wheel rotates counter-clockwise in the top view, and if the bottom wheel rotates clockwise in the side view, then the resulting controlled rotation will take place as shown in Figure 8. This method of actually pulling on the spin axis is satisfactory for use on the fixed wheel, but a different method must be used to torque the gimbaled wheel. The original arrangement of gears and a clutch plate to engage or disengage the gimbal is presently being modified along with the control stick. Upon completion of these modifications, the GASP should be ready for an inflight validation.

Validation Techniques

This validation will be performed under weightless conditions, utilizing the Aeronautical Systems Division zero-gravity research aircraft. The validation will consist of determining the capability of the GASP for beginning, sustaining, and stopping rotation about each principal axis; changing the axis of rotation; establishing desirable rates of rotation; stabilizing against random rotation; stabilizing for material handling; and stablizing as an aid for walking under weightlessness with adhesive footgear.

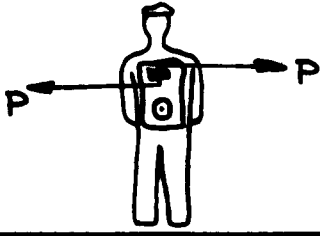| MANEUVER	BODY MOVEMENT	CONTROLLER MOVEMENT
PITCH UP (Side View)		
PITCH DOWN (Side View)		
ROLL LEFT (Front View)		
ROLL RIGHT (Front View)		
YAW LEFT (Top View)		
YAW RIGHT (Top View)		

Figure 7   Controller-Maneuver Coordination
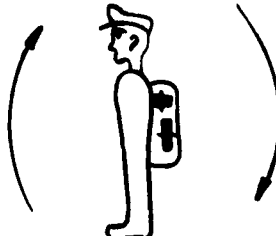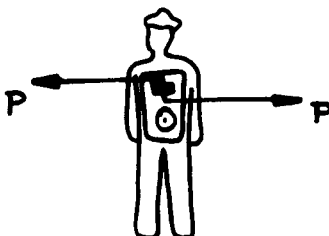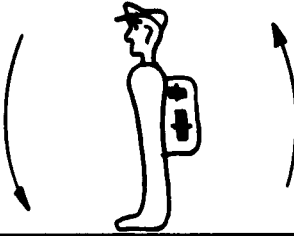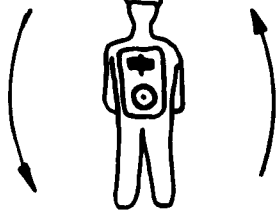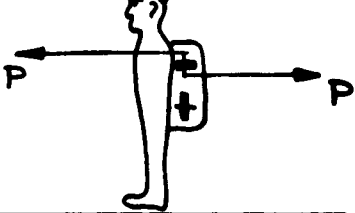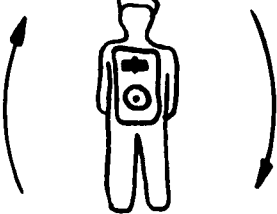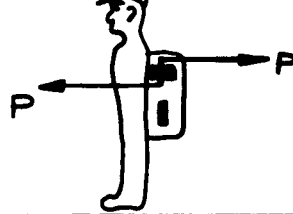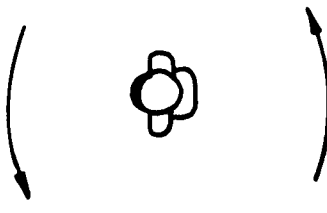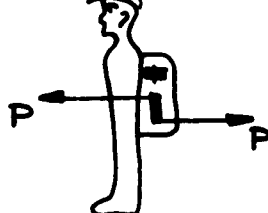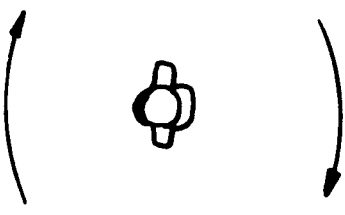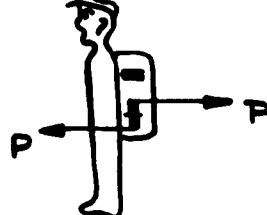
MANEUVER	BODY MOVEMENT	TORQUE APPLICATION
PITCH		
PITCH DOWN		
ROLL LEFT		
ROLL RIGHT		
YAW LEFT		
YAW RIGHT		

Figure 8 Maneuver - Torque Coordination

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A direct measure of the stability contribution of the GASP may be made by measuring the capability for applying certain torques while weightless and comparing them with the data already in existence for unaided free-floating personnel (ref. 1 and 4).

The information to be gleaned from these tests will be primarily the ease with which rotation may be controlled, and the ability of the GASP to provide tumble recovery capabilities. The capability for tumble recovery will be able to be evaluated since the gimbaled gyro will be equipped with a device whereby the operator may engage the gyros at will.

These controlled rotations and stability characteristics will be subjected to film analyses for most of the data. At the present time, it seems that the major inflight recordings will consist of a continuous readout of the velocity of each wheel and if possible, a continuous readout of the tension in the cables. Using these measurements and applying the equations given previously, the calculated rotational velocities may be compared with the actual filmed velocities to provide an overall efficiency evaluation.

In the actual calculations it will be necessary to know the quantities which remain constant, namely the spring constant, the torque arm, the moment of inertia of the rotor, and the moment of inertia of the operator and the GASP about the axis of intended rotation. The spring constant which is characteristic of the springs holding the fixed gyro is 25.56 lb/ft. for each spring. The torque arm for the fixed gyro in its initial configuration was measured to be 0.135 feet. The moment of inertia of each rotor was calculated to be 0.105 lb-ft-sec^2. The moment of inertia of the operator will differ between individuals. However, it can be calculated by using geometrical models constructed from anthropometric data (ref. 4); or in fact it could be measured with the use of a device to measure the period of oscillation of the human body.

In conjunction with this infligh. validation it may be constructive to organize a flight test plan that may be followed to attain the major human factors goals of this study (see Fig. 9). In this plan, the capability for controlled rotation and the capability for stabilization are both studied. The results should include optimum rotation rates and the magnitude of the available degree of stabilization. The abbreviations in Figure 9 are to be noted as follows:

PU - pitch upward in the sagittal plane
PD - pitch downward in the sagittal plane
RR - roll to the right in the coronal plane
RL - roll to the left in the coronal plane
YR - yaw to the right in the transverse plane
YL - yaw to the left in the transverse plane

The three rotor speeds should be selected such that the lowest speed will just sustain rotation, the highest speed within safety considerations, and the third choice in the middle. For the controlled rotation, approximately four trials should suffice for each maneuver. For the stabilization part of the test, approximately four torques should be applied about each axis at each rotor speed. This amounts to a total of 252 data gathering parabolas per subject. Therefore, approximately twenty flights would suffice to carry out this validation study.
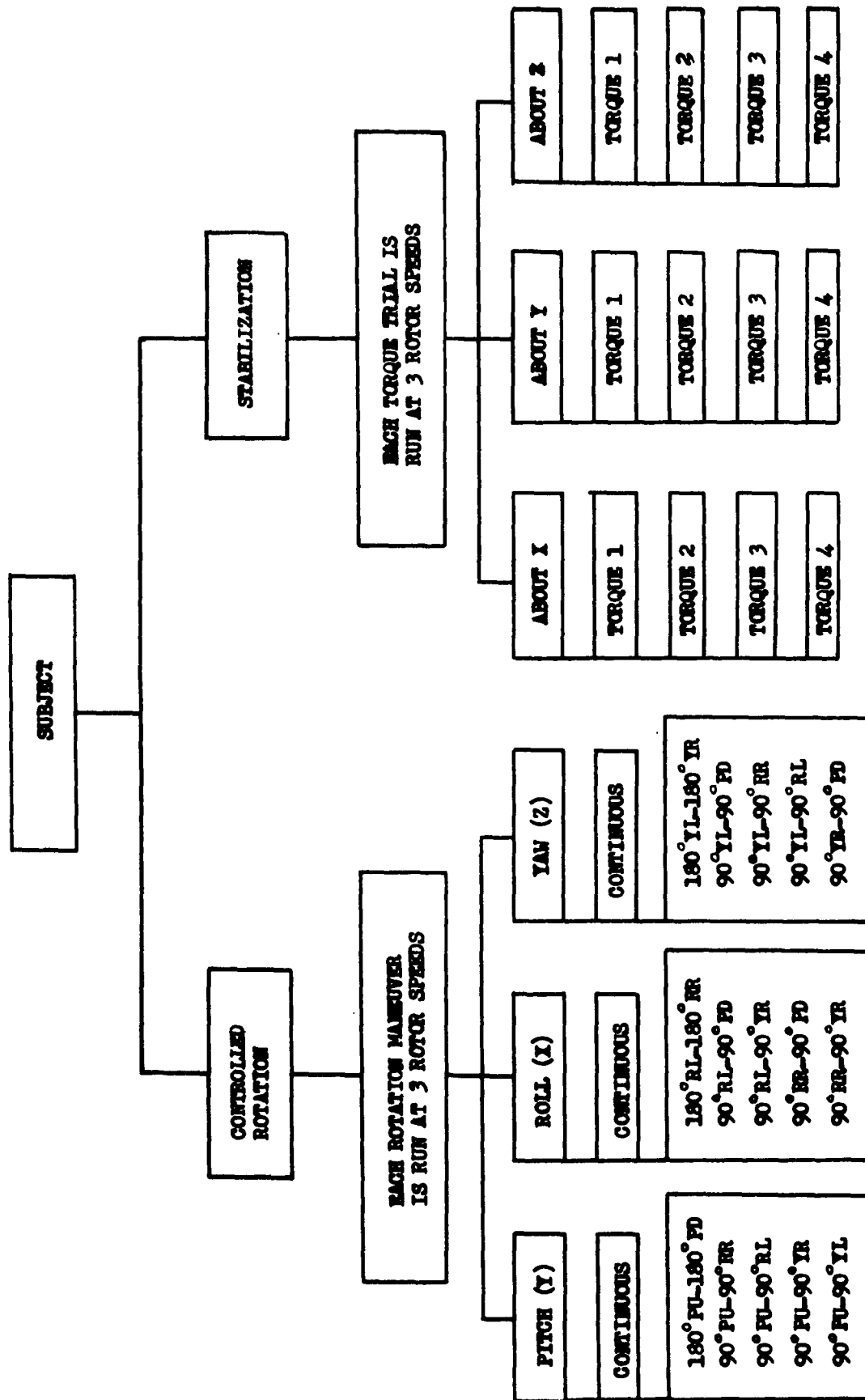
FIGURE 9   GASP FLIGHT TEST PLAN

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Human Factors Goals

This study describes first the mechanics of controlled rotation and then discusses some of the problems and procedures associated with effective operation of the GASP. It is fitting that some thought be given to that element which cannot be fully described quantitatively, namely, man himself. This section, then, relates a few of the human factors goals to be strived for in the study of the GASP; and also points out some of the areas of interest that will be important in more advanced studies of controlled rotation and stabilization for the orbital worker.

In general, there are three major objectives involved. Primarily, it is necessary to establish desirable rates of rotation, both for the gyro wheels and for the operator. In addition, it will be helpful to develop techniques for tumble recovery. Finally, it is intended to determine the optimum controller design.

It is known, for example, that a certain amount of rotation of the human body will cause disorientation and confusion such that the human operator would become helpless. In fact, there is a limit to the rate of rotation that a man may endure and still remain alive. Obviously, there are some spin rates that may be effectively tolerated with little or no decrease in performance. Therefore, in the design of a more advanced controlled rotation unit, the usable rate of rotation must be kept well within the rate which describes the threshold of disorientation. This threshold may be determined by noting the decay in performance using a standard motor task and a range of angular velocities. Likewise, there is a lower limit of rate of rotation if some work requires change of body attitude. This limit is influenced by energy consumption and time parameters. Disorientation, energy expended, and time of operation, then, are the primary factors in determining desirable rates of rotation of the operator. Safety is the prime consideration in finding an upper limit to wheel velocities. However, the required precessional velocity will determine the actual wheel velocity. These required precessional velocities have not as yet been determined for the GASP. The starter motor (shown in Fig. 5) will have to be adapted to provide a range of wheel speeds.

Tumble recovery is an area of vast importance to an orbital worker outside of his vehicle. The tumble is more complex than the previously mentioned rotations, in that the rotations may take place about more than one axis. The tumble could result if the wheels were disengaged, if the wheels were not rotating at all, or if the wheels were not rotating fast enough. If the wheels were gimbal mounted and were disengaged, the operator would rotate about his stabilization unit in a tumble. To recover from this type of tumble, the worker would merely engage the wheels by a clutch mechanism. If after engaging the wheels, the worker continued to tumble, he could accelerate or decelerate the wheels until rotation ceased. The present model of the GASP does not have this provision for accelerating the wheels. It is anticipated that more advanced models of a personal stabilization unit will contain either self-contined motors or some pneumatic device to rev the wheels up and keep them rotating. Presumably then, the operator will be capable of varying his rotor velocity; and hence he will be capable of attaining various degrees of stability.

If the operator found himself in a tumble with neither wheel rotating, he could not recover by means of the GASP, unless he could start the wheels rotating. If the operator found himself in a tumble with the wheels not rotating fast enough, he could accelerate the wheels until the tumble became stabilized. If the velocity of the wheels approaches a limiting saturation velocity and a turble began, the operator could

decelerate the wheels in order to provide stability. In any case, the worker must be in a position to evaluate the problem in order to attempt a solution. Again, disorientation may be a problem.

The third primary objective of the validation is to determine the optimum control of rotation. Factors involved in rotational control include response characteristics of the GASP, cross-coupling of the wheels, ease of torquing the gyros, command-response lag times between types of maneuvers, and ease of movement of the control stick. The response characteristics of the GASP refers to the previously mentioned phenomenon of induced rotations about axes other than the intended axis of rotation. This factor may have a marked effect on performance of the operator if the unexpected rotation occurs for a prolonged period or if the motion is unexpectedly quick. However, as the operator becomes familiar with the GASP, it is expected that this factor will become less important.

Cross-coupling of the wheels may also affect the operator's performance if it occurs unexpectedly. If this proves to be a significant problem, the number of wheels controlling each axis will have to be increased to remove the problem entirely.

Torquing the gyros may be a problem in that the operator must be able to transmit enough force to the axis of rotation; and a pressure-suited operator, being somewhat restricted in mobility, may have difficulty in operating the control stick. Conceivably, the operator's reaction time may be increased in the inflated condition. Therefore, his performance may also be affected by the placement of the control stick. The best location for this control is assumed to be at elbow height from the floor, in front of the operator, and slightly to the right of his plane of symmetry (sagittal plane). Various locations could eventually be tested for use in an advanced stabilization device.

Command-response lag times between maneuvers arise from the fact that the gimbaled gyro must be at right angles to the fixed gyro if a pitch or roll maneuver is to be performed. If the gimbaled gyro is not in this position when a pitch or roll command is given, it will precess to that position before the pitch or roll response is accomplished. Therefore, this delay in rotation may affect the operator's performance if the lag is significant.

The ease of operation of the control stick will be affected by control location, pressure-suit mobility, and wrist limitations in the rotary control mode. This factor will be resolved during the validation since it is vital to the efficient operation of the GASP.

Other factors involving the operator of a controlled rotation-stabilization system include effects of limb movement during a controlled rotation maneuver, location and use of a quick disconnect of the entire harness, ability to disengage the gimbaled gyros, a locking mechanism to prevent the wheels from exceeding a safe velocity, effects of a pressure suit on performance, and provision to closely monitor the flight tests so that the operator does not land on his back during a multi-g pullup.

BIBLIOGRAPHY

1. Dzondolet, E. and Rievley, J. F., _Man's Ability to Apply Certain Torques While Weightless_, WADC Technical Report 59-94, April 1959. AD 220 363

2. Griffin, James B., _A Study of a Self-Maneuvering Unit for Orbital Maintenance Workers_, ASD Technical Report 62-278, February 1962.

3. Simons, J. C. and Gardner, M. S., _Self-Maneuvering for the Orbital Worker_, WADD Technical Report 60-748, December 1960. AD 252 125

4. Whitsett, E., _Dynamic Analysis of Flexible Man_, USAFIT Master's Thesis, Aug. 1962, Air University, W-PAFB, Ohio.